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Does a trochanteric lag screw improve fixation of vertically oriented femoral neck fractures? A biomechanical analysis in cadaveric bone

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ABSTRACT

Background: We assessed the biomechanical performances of a trochanteric lag screw construct and a traditional inverted triangle construct in the treatment of simulated Pauwels type 3 femoral neck fractures.
Methods: An inverted triangle construct (three 7.3-mm cannulated screws placed in inverted triangle orientation) and a trochanteric lag screw construct (two 7.3-mm cannulated screws placed across the superior portion of the femoral neck and one 4.5-mm lag screw placed perpendicular to the fracture in superolateral to inferomedial orientation) were tested in nine matched pairs of non-osteoporotic human cadaveric femora. We used a previously described vertically oriented femoral neck fracture model and testing protocol that incrementally loaded the constructs along the mechanical axis of the femur to 1400 N. Specimens that survived incremental loading underwent cyclic loading. Apparent construct stiffness, force at 3 mm of displacement, and survival of incremental loading were recorded.
Findings: The trochanteric lag screw group had a 70% increase in stiffness (261 N/mm [29 standard deviation] versus 153 N/mm [16 standard deviation]; $P = 0.026$) and a 43% increase in force required for displacement (620 N versus 435 N; $P = 0.018$) compared with the inverted triangle group. One trochanteric lag screw and no inverted triangle specimen survived incremental loading.
Interpretation: A trochanteric lag screw construct applied to vertically oriented femoral neck fractures provides marked improvement in mechanical performance compared with the inverted triangle construct.

1. Introduction

Femoral neck fractures in young adults usually are the result of high-energy trauma. The treatment of choice for these injuries is anatomic reduction with internal fixation, with care taken to preserve the blood supply to the femoral head. Treatment is fraught with high rates of osteonecrosis (10% to 45%), nonunion (10% to 30%), and loss of fixation (8% to 19%, depending on method of fixation) (Massie, 1973; Protzman and Burkhalter, 1976; Swiontkowski, 1994; Tooke and Favero, 1985). In the absence of anatomic reduction with stable implants, the rate of osteonecrosis rises considerably (Massie, 1973).

The fracture pattern of high-energy femoral neck fractures often is oriented in a more vertical direction than are the patterns of fractures in osteoporotic, low-energy femoral neck fractures (Leighton, 2005). Vertical orientation of a femoral neck fracture subjects the fracture to more shear forces rather than the compression forces observed with more horizontally oriented fractures. Pauwels classification of femoral neck fractures assigns the most vertical fractures as type 3, or greater than 70° from the horizontal (Bartonícek, 2001). Fixation of Pauwels type 3 femoral neck fractures has been particularly problematic (Massie, 1973; Protzman and Burkhalter, 1976; Swiontkowski, 1994; Tooke and Favero, 1985).

One option for treating high-energy femoral neck fractures is open reduction and pinning using cannulated screws. Although the technique of using three parallel, partially threaded screws in an inverted triangle orientation (the traditional inverted triangle construct) is common, a construct of a lag screw perpendicular to the fracture in combination with two parallel cannulated screws into the femoral neck (the trochanteric screw construct) has also been used (Virkus et al., 2009).

To our knowledge, no biomechanical study has assessed which of these two screw constructs provides superior mechanical performance for fixation of vertical femoral neck fractures. The purpose of this study was to compare the biomechanical stability of the two internal fixation techniques for stabilization of non-osteoporotic Pauwels type 3 vertical femoral neck fractures. Our hypothesis was that the technique using a screw perpendicular to the fracture plane would have improved mechanical performance compared with the traditional technique.

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2. Methods

2.1. Fracture model

Nine fresh-frozen, matched human proximal femur specimens were used. The bone mineral density of each specimen was measured by dual energy x-ray absorptiometry to ensure all were non-osteoporotic, which was defined as a T-score of −2.5 or higher. The average T-score of the samples was −0.83 (standard deviation [SD] = 1.23). In addition, radiographs revealed no evidence of tumor, previous fracture, or other bony pathological abnormalities. The specimens were cleaned of soft tissue and stored at −20 °C. Each specimen was slowly thawed at room temperature and kept moist with saline throughout instrumentation and testing.

Under fluoroscopic guidance, an oscillating saw was used to partially create a vertical osteotomy in each specimen (Fig. 1). The osteotomy was initiated at the superior femoral neck and was extended toward the distal-most basicervical region. Guidewires for the cannulated screws were then placed for both implant groups. The oscillating saw was used to complete the osteotomy, beginning at the distal-most basicervical region and progressing superiorly to meet the end of the initial cut. This process was used to maximize anatomic reduction of the fracture once implants were placed.

2.2. Fracture fixation groups

Instrumentation of all specimens was performed in the operating rooms of a level I trauma center. The procedures were performed by a single orthopedic trauma fellow under direct supervision of an academic orthopedic traumatologist in an attempt to closely approximate how the surgery would be performed in a patient. Image intensification was used in all cases to ensure proper placement of screws in coronal and sagittal planes.

Two surgical constructs were used to fix simulated Pauwels type 3 femoral neck fractures. In the inverted triangle construct group, three 7.3-mm cannulated screws (Synthes, Paoli, PA, USA) were inserted parallel into the femoral head in an inverted triangle configuration, as is commonly done for lower energy femoral neck fractures (Fig. 2) (Yang et al., 2013). The most inferior screw was positioned along the inferior neck in the calcar region, with a starting point above the lesser trochanter. The two cephalad screws were inserted more superiorly, close to either the anterior or posterior cortices of the femoral neck and 5 mm from subchondral bone in the femoral head (Fig. 2).

In the trochanteric lag screw construct group, two parallel, partially threaded 7.3-mm cannulated screws (Synthes) were placed across the superior portion of the femoral neck, as they had been in the inverted triangle construct group. Then, a 4.5-mm screw was placed perpendicular to the fracture site, using a standard lag technique, in a trajectory from superolateral to inferomedial (Figs. 2 and 3).

Fig. 1. Creation of a vertical osteotomy.

2.3. Testing protocol

The femoral shaft of each specimen was placed in an MTS cylinder (MTS Systems Corporation, Eden Prairie, MN, USA) and was potted with polymethylmethacrylate bone cement. The cylinder was then secured to a fabricated metal wedge to allow the specimen to be loaded in 25° of adduction to simulate single-leg stance, as previously described (Aminian et al., 2007). Specimens were loaded vertically with a 10-mm flat aluminum plate centered over the femoral head (Fig. 4). We followed the mechanical testing procedures previously used by Aminian et al. (2007) to facilitate direct comparisons across studies. Specifically, specimens were loaded monotonically in compression at a displacement rate of 1 mm per minute until catastrophic failure or until 1400 N was reached. Specimens that survived were cyclically loaded with a force of 1400 N at a frequency of 3 Hz until failure. For each specimen, the mode of failure was recorded.

2.4. Analysis

We computed an apparent construct stiffness (simply referred to as "stiffness" below) for each sample by creating a best-fit line in the linear region of the force–displacement curve for each sample. The force required for 3 mm of vertical displacement for each of the samples was also recorded. A paired Student's *t*-test was conducted, and a $P < 0.05$ was defined as significant. All statistics were calculated with the use of SPSS software (SPSS Version 14; SPSS Inc., Chicago, IL, USA).

3. Results

A 70% increase in apparent construct stiffness was observed in the trochanteric lag screw construct group (mean, 260.7 N/mm [29.4 SD]; range, 175.7–440.3 N/mm) compared with the inverted triangle construct group (mean, 153.4 N/mm [15.5 SD]; range, 65.4–202.4 N/mm) ($P = 0.026$) (Fig. 5). A 43% increase in the force required for 3 mm of vertical displacement was also observed in the trochanteric lag screw construct group (trochanteric lag screw construct mean, 620.2 N [57.6 SD]; range, 488.5–998.6 N; inverted triangle construct group mean, 435.0 N [39.7 SD]; range, 214.9–591.1 N; $P = 0.018$) (Fig. 6).

One specimen from the trochanteric lag screw construct group survived incremental loading and failed during the cyclic loading portion of the protocol. None of the inverted triangle construct specimens survived incremental loading. As expected, all constructs failed under shear forces (Fig. 7).

4. Discussion

Vertical femoral neck fractures represent a great challenge for the orthopedic traumatologist. Treatment is fraught with increased likelihood of nonunion and loss of fixation (Massie, 1973; Protzman and Burkhalter, 1976; Swiontkowski, 1994; Tooke and Favero, 1985). The great number of implants studied for the treatment of this fracture belies the fact that controversy exists regarding the ideal implant to use (Aminian et al., 2007; Baitner et al., 1999; Liporace et al., 2008).

Screw fixation is thought to have certain technical advantages over fixed-angle devices. These advantages include ease of insertion without concern for loss of reduction while inserting a large screw with a large torque that tends to displace the fracture. However, traditional lag screws are thought to have poor biomechanical performance. To address this concern, multiple centers, including ours, have been using a lag screw oriented perpendicular to the fracture in an attempt to